How HF-Surface radar & HF-OTHR and GPS Technology and Infrasonic Imaging can favourably be implemented for detecting the On-set of Tsunamis and real-time imaging of its spreading

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Abstract

Worldwide, medium to short term tsunami prediction is becoming ever more essential for safeguarding man due to an un-abating population increase within low-lying coastal regions of all of the affected oceans. But hitherto there have been no verifiable methods of reliable tsunami prediction developed - except for a few isolated examples of placing arrays of costly short-lived sensors along the ocean bottom requiring monthly re-calibration efforts. This dilemma is a result of not yet having identified the proper approaches to tsunami prediction. The question on whether there do exist reliable prediction methods was answered long ago by fauna living within the coastal littoral zone that is affected by tsunamis. Especially during the last devastating "Boxing Day 050426 Tsunami" caused by the Sumatra-Andaman "Super-Earthquake" of M = 9.3 with epicentre near Simeulue Island, there were many verifiable episodes on how fish escaped the affected coastal region in time; the elephants, water-buffalos and other non-domesticated animals rushed for higher ground locations well in time before the tsunami crest and subsequent swells approached, and so on.

These observations provide proof that some electromagnetic or, more likely, infrasonic local warning signatures are received by these creatures relatively long before the approaching tsunami strikes. We presume that the signatures could be infrasonic waves travelling at high speeds as under-water surface waves that could be detected by marine fauna as well as coastal animals and birds. Tsunamis have existed for millions of years and fauna of the affected coastal region has developed instinctive warning mechanisms that we need to explore.

Another promising natural sensor may utilize electromagnetic precursor signatures that yet need to be fully discovered. Both, the role electromagnetic phenomena and the role infrasonic signatures will be scrutinized. The results of successful post-event model reconstructions of viable electromagnetic and infrasonic precursor signatures will be presented.

1. INTRODUCTION

The two largest super-earthquakes along the Indo-Australian and south-eastern Eurasian plates of the past forty years provided invaluable riche precision measurement data – seismic, electromagnetic and infrasonic in nature – as well as satellite altimeter recordings which are here being scrutinized for developing a viable hazard mitigation approach for the inevitable reoccurring tsunami hazards [1]. The first of these devastating candidate earthquakes occurred at the southern extension of the Nicobar – Andaman island chain on *"Boxing-Day 2004"* (M = 9.3, 00:58:53 UT, 3.3° N, 96° E) near Simeulue Island causing a rupture of about 1300 km with a 10 m vertical subduction slip at the depth of 30 km along the Andaman Microplate of the East Indian Ocean all the way up to Myanmar (Burma). It resulted in more than 290,000 deaths and over 3,000 coastal villages being almost completely destroyed along the shores of the Eastern Indian Ocean. The second earthquake episode occurred on 2005 March 23 (M = 8.7 (+ 8.6), 16:09:36 UT, 21° N, 97.8° E) at the slightly more southern island of Nias as the main aftershocks of the main shock, which were not vertical but a lateral slips, thus generating only minor tsunamis. The total energy released by these two electromagnetically related earthquakes exceeded 4.3×10^{18} Joules (equivalent to a 100+ Giga-ton nuclear explosion), being equivalent to energy consumed within 10 months in the extended EU. The vertical slipping finally reached after several months a cumulative slip of 16 m near Banda Aceh at the northern tip of Sumatra. This super-earthquake episode displaced more than 30 km^3 of sea-water, raising the global ocean sea level by .2 mm, and enlarging the average earth radius by 2.3 cm [1, 2].

The main shock caused a generation of vertical tsunami waves travelling in all directions from its origin at Simeulue Island into the Indian Ocean with average ocean wave height of about 1 m; reaching into the mouth of the Malacca Strait, into the northern reaches of the Bay of Bengal, into the western Indian Ocean up to Somalia and into the Arctic Ocean, finally reaching the Pacific as well as the Atlantic oceans. It was recorded that the tsunami crest heights exceeded 10 m, and subsequent swells reached 15 m at a few shore locations, whereas the receding anti-swells were dipping down by more than 12 m at some large coves with 10 m dip in average.

2. Other Recent Terrestrial Tsunami in Comparison to the 2004 Simeulue M = 9.3 and the 2005 Nias M = 8.7

During the past fifty years there were other major devastating tsunamis of comparable sizes to the candidate super-earthquakes such as those, for example, in 1952 at the Kamchatka, M = 9.1; in 1957 at Andreanov Island M = 9.2 in the Aleutian islands; the most devastating 1960 Southern Chile M = 9.4; the 1964 Prince William Sound M = 9.1 near Anchorage, Alaska. These super-earthquakes ruptured mega thrust plate boundaries similar to the Sumatra-Andaman event along the Andaman micro-belt subduction zones. These and previous and/or future giant earthquakes occur where large oceanic plates under-thrust continental margins involve fault zone areas, typically 200km wide and by +/- 1000 km long with 10 + m vertical slips. Past history shows that one of the most active subduction mega thrust plate boundaries is along the Indo-Australian Plate along the Andaman Microplate extending from south-western Sumatra via the Andaman Miniplate to north of Myanmar (Burma) into the Himalayan eastern frontal thrust with giant earthquakes of M > 8.7 at 20 – 60 year repetition rates [1, 2]. Commonly, these major main shocks – causing the tsunami due to the vertical slip - are followed by duplets of lateral shift aftershocks rarely generating additional major tsunamis. Only most recently was it discovered that there exist major geo-electromagnetic forces creating abnormally super-high variations of the local geo-magnetic fields which appear as if they were caused by equivalent subsurface current sources, below 10 – 30 km, exceeding 10^6 Amperes. These findings need to be explored in greatest detail during forthcoming giant mega thrust plate earthquake episodes subject to improving the global geomagnetic measurement network.

However, not all earthquakes generate tsunami and those that do must satisfy certain characteristics [3]:

- the epicentre must lie underneath or near an ocean subduction zone
- fault vertical movement of the sea floor must be of several meters (6 – 10 m) over a large area (~ 30,000 km^2 to over 100,000 km^2) and of great length (300 – 1000 km and more)
- the main-shock magnitude must be high (above 7.5) and of shallow focus (less than 40 km)

A tsunami consists of a series of acoustic ocean waves of extremely long wavelength generated mainly by earthquakes occurring below or near the ocean floor causing vertical slip deformation. The associated wave motions are of three major types [3]:

- *Sound waves*
  - Longitudinal compressional waves
  - Compression-rarefaction waves
  - Common acoustic water waves
- *Vertically transverse waves*
  - Light waves
  - Gravity waves
- *Horizontally transverse waves*
  - Rossby waves

Ocean waves need to be distinguished by their wavelength: extremely long (tsunami) versus very short (capillary) waves:

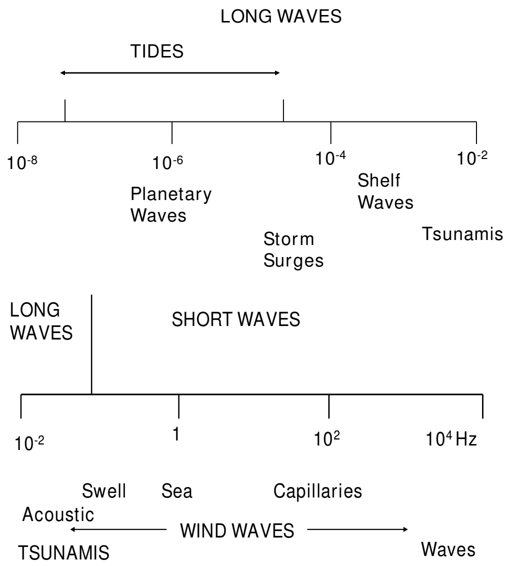

Fig. 1, Spectra of short and long waves (in Hz)

For the vertical transverse tsunami waves the velocity is given approximately by $v_t \sim (g\ D)^{1/2}$ with g denoting acceleration due to gravity (gravitational constant), and D the averaged local ocean depth, respectively. Thus, the deeper the ocean, the faster the tsunami wave will travel. At a depth of 7 km the velocity reaches about 950 km/hr with a wavelength of about 290 km, whereas at a depth of 2 km the velocity reduces to 500 km/hr with a wavelength of 150 km. As the tsunami travels across the ocean, the velocity and the wavelength change proportional to ocean depth – at times slow and then also very rapidly depending on the ocean bottom topography – and once it reaches shallower inclined, slowly sloping coastal transition zones at about 10 m depth, the velocity reduces to about 36 km/hr with a wavelength of about 10 km. Meanwhile the wave height increases sharply from less than a meter at depths of about 5 km to several meters, reaching heights of 15 to 20 m [4]. In summary, the tsunami on a wide open ocean consists of a series of travelling waves that may last for hours. The enormous outflow of coastal water, succeeding the approaching tsunami crest and that of subsequent tsunami waves, usually cause more damage than the incoming wave fronts; and the first crest reaching several meter height is not always the largest and is commonly superseded by the second and third approaching tsunami waves depending on the local coastal ocean bottom slope characteristics. Thus an approaching tsunami displays three general appearances [1 - 4]

- a sudden fast rising tide

- a subsequent withdrawal of coastal ocean sea water
- a cresting wave of steep and almost vertical slope of several meters height
- a series of bores with step-like changes in water level rises that advance rapidly and with slow intermittent withdrawals at times of several minutes up to 20 minutes of the coastal inundating water in between that can lat for several hours.

3. Continental Drift and Plate Theory – Expansion of Terrestrial Planet Caused by Continuing Successive Super-Earthquakes and Tsunami

Both large earthquakes and tsunami make themselves felt around, through and across the entire terrestrial sphere, deep down into the mantle and high up through the atmosphere, mesosphere and beyond the ionosphere. It was Alfred Wegner who first explored and introduced the Continental Drift concept in 1912 also discovering most of the boundaries between plate zones, assuming a constant earth radius. It was then Otmar C. Hilgenberg in 1932 questioned the constant earth radius postulate, demonstrating that an early "*crustal earth model*" of one third of the current earth-radius could be assumed and that all continental blocks could be adjusted in a puzzle-fit manner on the assumed model surface. The model of an expanding earth with coincident creation of the oceans was revived in the 1960's together with the modern tectonic plate theory including plate subduction, lateral shifts, rotations, and so on [5].

In the meantime, seismological metrology and instrumentation technology have advanced to almost the physical limits of perfection, and a global seismic network with digital equipment is in place. The existence of such an enormous global network of seismic instrumentation on ground and also on the ocean sea bottom came very handy for collecting extremely precise and exhaustive seismic signatures for the two great earthquakes at Simeulue of 2004 December 26 and the aftershock duplet at Nias of 2005 March 28 plus all the intermittent and post-event earthquake swarms. The observed seismic signatures assisted in obtaining a highly improved solid earth model of the earth's interior; and the observed earth's free oscillations, lasting for a very long time (over one year), allowed the precise determination of the earth' surface height increase by about 0.1 mm, the ocean sea surface increase by about 0.2mm, and that of the earth's mean radius by slightly more than 2.3 cm [1]. So we may conclude that with every giant earthquake and resulting tsunami the earth is expanding in surface area, ocean water volume and radius which require further analyses. However, the state of perfection of geo-electromagnetic instrumentation and of a global geo-electromagnetic measurement network, which allows precise polarimetric 3-axis geomagnetic flux-gate measurements from at least 10 mHz up to about 20 Hz is unfortunately in a very poor and imperfect state. The existing INTER-MAG (enabling total power measurements of the quasi-static geo-magnetic field below 0.1 mHz) is of little use because seismo-geoelectromagnetic signatures do not exist at frequencies below 10 mHz. The desirable global geo-electromagnetic metrology network (10 mHz up to about 20 Hz) does not exist, must be added and created in order to obtain a complete understanding of the intricate tectonic stress-change events which are directly coupled to geo-electromagnetic phenomena - still to be explored throughout this twenty-first century.

4. Geo-Electromagnetic Ground to Ionospheric Disturbances due to Earthquakes and Tsunami

In a companion paper it was deliberated that there exist undoubtedly verifiable geo-electromagnetic phenomena at the lithospheric to ionospheric levels that can be related to earthquakes. The underlying phenomena are not at all understood and require extensive local to global research investigations and with it highly improved geo-electromagnetic instrumentation.

It is well known that the ionosphere can be affected by a great variety of external disturbances such as the solar wind and the inter-galactic magnetic field variations with subsequent solar-magnetic storms, and so on, as well by internal (to ionosphere) earth generated phenomena such severe weather with mega-volt lightning discharges to ground (*Blitz*) and to the ionosphere (*Spritzer – sprites*); including cyclones (*hurricanes or typhoons*), activating and active volcanoes, and so also due to major tectonic stress-changes like earthquakes with at times subsequent tsunamis [6, 7]. Although the ionosphere is primarily affected by solar and magnetic disturbances, while solid earth phenomena are generally minimal in comparison; there now exists increasing verifiable evidence observed by ionosondes and high frequency (HF) Doppler radar sounding systems that at times strong transient disturbances occurred in the ionosphere as a result of various tectonic stress-changes and especially the greater and in particular the giant earthquakes such as the Simeulue of 2004 December 26 and the aftershock duplet at Nias of 2005 March 28 plus all the intermittent and post-event earthquake swarms [1, 2, 8].

More recently, aeronomists analyzing high precision data recorded at numerous ground-based cartographic mapping stations of the Global Satellite Positioning Systems (GPS (USA), GLONASS (RF), GNSS (EU)) have observed ionospheric disturbances of the electron content of the ionospheric E & F layers, and the total electron content (TEC) triggered by various tectonic stress-changes including earthquakes and volcanic activation phenomena as well as the vertical transverse acoustic/gravitation tsunami waves [6 - 9]. As regards the tsunami waves, acoustic gravity waves generated at the ocean sea surface travel vertically through the atmosphere, mesosphere and interact with the E & F-layers causing ionospheric disturbances. The time varying TEC along the slant range from the HF Surface Radar (HFSR) as well as Over-The–Horizon HF-Radar (OTHR) toward the affected ionosphere and from GPS-Satellite to a ground-based receiver station can be employed to detect far-distant ionospheric variations above the locally activated tectonic stress-change (earthquake) or tsunami region, denoted as the Tsunami Ionospheric Disturbances (TID). Approximating the ionosphere shell height as 350 km in the equatorial region, then the intercept of the slant path on the ionospheric shell surface can serve as a monitoring station floating at an ionospheric point above the tsunami wave peak location [8]. As regards the transient tsunami description, it is then possible not only to determine the local tsunami wave-peak-point along its outward travelling route but at the same time the associated velocity of travel, except that the TID peak lags the tsunami by several minutes when the GPS approach is implemented due to a time lag in charging up the E & F layers.

5. COMPARISON OF RESULTS IMPLYING THE GPS AND THE HF-RADAR APPROACHES

Several independent research teams, first in Japan (Masashi Hayakawa et al.) [6] and in Taiwan (Jann-Yenq *(Tiger)* Liu et al.) [7, 8], then in Indonesia [9] and in India (A. DasGupta et al. [10] and A. K. Gwal et al. [11]) and now also elsewhere [3], analyzed the GPS signature variations due to the *"Boxing Day 2004 Tsunami"* and calculated the resulting TID from which they determined its travel history including travel speed and the time-dependent local tsunami wave peak location. Here the results obtained by the first four research groups will be compared and analyzed using *"Tiger Liu's"* method [8] as base standard; and it was found that all of the major approaches provide similar results. Although the HF Surface Radar and OTHR systems provided real time imaging, only qualitative results can be shown here due to the *'closed nature'* of the imaging systems and the real measurement data not being made available for open distribution [12].

In addition, there exist several other proposals for space borne satellite constellations of altimeters utilizing various orbiting satellite navigation and altimeter systems for mapping tsunami fronts across the oceans. One such proposal is the PARIS concept of ESA based on a passive reflectometry and interferometry approach (ESA Journal, 1993 December) implementing a constellation of 10 PARIS altimeters with the use of GPS, GNSS, Egnos, Galileo and GLONASS which deserves further attention [13].

6. INFRASONIC SURFACE WAVE DETECTION OF TRAVELING TSUNAMI WAVE PEAKS

The highly efficient infrasonic method for detecting close (several km) to far distant (several 1000 km) impulsive and turbulent disturbances for implementation in peaceful applications was long overlooked [14].

Infrasound is the range of acoustic frequencies below the audible range - typically below 25 Hz [lowest frequency on a piano keyboard is A^1 27.5 Hz, and an acoustic frequency of I Hz is 8 octaves below middle C^4 of 261.63 Hz (according to the American scale)] - where the thresholds of human hearing and feeling cross over. Large animals like elephants, rhinoceros, moose, water buffalo, and so on, may be able to detect and recognize frequencies well below the human audible threshold, down to several Hertz within the near infrasound range. There exists a rational analog between sound and the relationship of infrasound to light. Thus, one may call the frequency range 1 (3) – 20 (30) Hz near infrasound – similar to near infrared - and the range from about 0.05 (0.03) – 1 (3) Hz infrasound; and below 0.03 Hz, where gravity becomes important for propagation, and atmospheric waves are commonly denoted as acoustic/gravity waves, and so on [14]. A critical breakthrough for being able to measure infrasound was the development of effective noise and turbulence reduction methods which was achieved in the early 1960's by introducing noise-reducing pneumatic line-microphones consisting of impedance-matched resonant pipes along a pneumatic hose. An infrasonic noise reducer and signal receiver looks very much like an octopus with the center head section containing the electronic signal reception and pre-processing electronics from which up to twelve black porous hoses up to 30 m (50 m) in length are protruding straight outwards with equisectorial radial spacing of 30°, and resonant pipes of differing height (like organ pipes) and ports spaced along this acoustic transmission line about 20 cm apart and covering a planar radial area of 60 – 100 m diameter. Several of these basic noise reducers are laid out in linear or circular patterned arrays depending on application, and a rather complex signal collection and processing system was developed in order to detect minute acoustic disturbances over a semi-spherical observation space with highest directional (a few grade-seconds) and very large radial distances (n1000 km) and high detection accuracy (several meters). Great efforts have been and are currently further expended by Professor Dr. Alfred J. Bedard of the University of Colorado, Center for Interdisciplinary Research in Environmental Sciences (UC-CIRES) – formerly with NOAAA-ETL Infrasonic & Acoustic Sensing Laboratory - for further advancing these infrasonic high resolution imaging techniques for detecting severe down-bursts, avalanches, tornadoes, explosions, moving vehicles at close to far distant ranges including meteor impacts with the ionosphere, and so on [14 – 16]. By combining Polarimetric Meteorological Radar & Infrasonic Array sensor technology, severe storm analyses including the early detection of tornadoes were advanced [17]. In particular, the far distant detection of earthquake episodes, of activating volcanoes, and also of tsunami frontal movements - from shore side sensor locations - was demonstrated [14 – 16].

Extensive high precision Infrasonic Arrays have also been deployed in all of the major oceans – the Atlantic, the Pacific, the Indian, the Arctic and the Antarctic Oceans – as part of the International Monitoring System (IMS) of the Comprehensive Nuclear-Test-Ban Treaty (CTBT), and have been in use for the past thirty or more years. It turned out from long-term uninterrupted continuous around-the-clock monitoring operations that these rather humongous instrumentation facilities are very well suited for detecting close to far distant earth & sea quakes, volcano activation and also tsunami events. There also exist several of these Infrasonic Arrays in the Indian Ocean and down to the adjacent Antarctic Ocean [18] which were able to detect infrasonic signatures created by the candidate tsunami – (1) the arrival of seismic P, S, T waves of the earthquakes at Simeulue on 2004 December 26 and the swarm of immediate mini-aftershocks as well as those of the Nias main aftershocks of 2005 March 28, and so on; (ii) the direct incoming responses from the outward radiating front of the tsunami wave peaks, across the Indian into the Ant-arctic Ocean; (iii) secondary and tertiary arrivals of ducted acoustic gravity waves through the atmosphere, in the ocean, coupled into ocean bottom and re-appearing again, and so on. Although it was found that there exist subtle differences of the observed candidate signals between the low infrasonic range of 0.02 (0.03) Hz – 0.1 (0.3) Hz, the medium range of 0.3 (0.5) – 3 (5) Hz, and the upper range or near infrared range of 3 – 20 Hz, responses were received for all of the candidate Simeulue and Nias events, respectively, with signal strength of the much smaller Nias tsunami being far less than that of the mighty Simeulue tsunami [18].

The tsunami source location near the earthquake epicentres, in conjunction with the unique signatures observed at the various Infrasonic Array stations of the Indian and Antarctic Oceans, strongly suggest that Infrasound combined with other HF-radar, OTHR and GPS techniques such as the PARIS concept [13], may provide an essential discriminator for tsunami genesis and tsunami wavefront propagation.

7. CONCLUSIONS AND RECOMMENDATIONS

We have introduced for consideration various viable geo-electromagnetic ionospheric HF-Radar, OTHR, and GPS dynamic monitoring techniques for determining the outward radiating front of the ocean sea surface tsunami wave peak, complimented by the novel Infrasonic Imaging technique for disturbances that may be related to tsunamis. Indeed, extensive fundamental research is now in desperate need for advancing our understanding of these promising techniques which at the same time will require the dedicated advances of instrumentation, real time in situ processing and interpretation techniques. In addition, there exist various novel ground-based electromagnetic precursor signature recording techniques within the ULF/ELF electromagnetic frequency ranges as well as the RP-Diff-POL-IN SAR high-altitude drone and space borne satellite methods – discussed in another companion review paper – which need to be integrated for ultimately discerning the proper hazard mitigation inputs.

Thus, we do not at all agree with the common view adopted by venerable seismologists that earthquake and tsunami prediction can never be done and is out of reach - albeit based on their seismological approaches only. Yes, we agree that *"Natural hazards are inevitable"*, but we are confident to state that also in the case of earthquake and tsunami hazards we can reduce the impact of natural disasters which are not inevitable subject to implementation of alternative electromagnetic and infrasonic sensor modalities in order to utilize hitherto neglected seismo- electromagnetic, GPS, HF radar and infrasonic signatures which were scrutinized in this and the companion overview papers.

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REFERENCES

[1] Hanson, B. (Inv. Ed.), 2005, Special Issue on « *The Great Sumatra-Andaman Earthquake – Learning from Natural Disasters* », Science, Vol. 308, No. 5725, pp.1125 – 1146, 2005 May 2005: see separate papers

[2] Widarto, D. S., 2006, Lithospheric Seismo-electromagnetic phenomena in the Great Sumatran Fault Zone, Indonesia, in preparation (Report of LIPI, Geophysical Institute of Indonesia, Bandung, Indonesia).

[3] Murty, T. et al., 2006, Vertically transverse long gravity waves in the ocean as a natural hazard, Overview presented at the IGU Annual Convention, Bhopal, India, 2005 December 06 – 09 (to be included in the proceedings).

[4] Chadha, R. K., 2006, Vulnerability of the Indian coast to Tsunami Threat, Overview presented at the IGU Annual Convention, Bhopal, India, 2005 December 06 – 09 (to be included in the proceedings).

[5] Sen, S., 2006, EARTH – the planet extraordinary, Overview presented at the IGU Annual Convention, Bhopal, India, 2005 December 06 – 09 Overview presented at the IGU Annual Convention, Bhopal, India, 2005 December 06 – 09 (to be included in the proceedings).

[6] M.Hayakawa, (Ed.), 2006, Proceedings of IWSE-05 (International Workshop on Seismo-Electromagnetics), University of Electro-Communications, UEC Chofu-Shi, Tokyo, Japan, 2005 March 15 – 17, TERRAPUB, Tokyo, (in final printing)

[7] Tsai, Y.-B. and J.-Y. Liu, (Eds.), 2004, Special Issue on Earthquake Precursors, TAO (Terrestrial, Atmospheric and Oceanic Sciences), Vol. 15, No, 3, I-IV, Meteorol. Society of Taiwan (ROC), Taipei, 564p.
[8] Liu, J-Y. (Tiger), et al., 2006, Ionospheric GPS TEC disturbances triggered by the December 26 2004 Indian Ocean tsunami, Proceedings of IWSE-05 (International Workshop on Seismo-Electromagnetics), UEC Chofu-Shi, Tokyo, Japan, 2005 March 15 – 17, TERRAPUB, Tokyo, (in final printing), 8 p.
[9] Widarto, D. S. et al, 2006, Seismo-Electromagnetic Signatures Associated with the Earthquakes During the Period of 1997-2000 in the Southern Part of Sumatra Island, Indonesia, Proceedings of IWSE-05 (International Workshop on Seismo-Electromagnetics), University of Electro-Communications, UEC Chofu-Shi, Tokyo, Japan, 2005 March 15 – 17, TERRAPUB, Tokyo, (in final printing), 6p.
[10] DasGupta, A., A. Das, D. Hui, 2006, Ionospheric disturbances observed by the Indian East Coast GPS stations following the 2006 December 26 Sumatra-Andaman Earthquake, Overview presented at the IGU Annual Convention, Bhopal, India, 2005 December 06 – 09 (to appear in its Proceedings – in completion).
[11] Gwal, A. K., S. Sarkar, Sh. Bhattacharya and M. Parrot, 2006, Ionospheric responses to the Sumatra Earthquake observed by the DEMETER Satellite, Overview presented at the IGU Annual Convention, Bhopal, India, 2005 December 06 – 09 (to appear in its Proceedings – in completion).
[12] Anderson, S. J., 2005, Prospects for tsunami detection, mapping, and characterization using the Surface and OTHR HF Radar systems, DSTO Internal Report, DATO, Salisbury , SA, Australia.
[13] Martin-Neira, M. et al., 2005, Detecting tsunamis using the PARIS concept. Proceedings URSI-B, SMRS-05 (Microwave Remote Sensing of the Earth, Oceans, Ice and Atmosphere), ESA-JRC, 2005 April 20-21.
[14] Bedard, A. J., 2005, Low-Frequency Atmospheric Acoustic Energy associated with Vortices produced by Thunderstorms, Monthly Weather Review, Vol. 133, No. 1, pp. 241 – 263, January 2005
[15] Bedard, A. J., 1971, Seismic response of infrasonic microphones, J. Res. NBS. Vol 75C, pp. 41 – 45, 1971.
[16] Bedard, A. J., T. M. Georges and G. E. Greene, 1975, Infrasound from Convective Storms, Part IV: Is it useful for warning?, J. Appl. Meteor. Vol 14, 1303 – 1316, 1975.
[17] Hubbert, J. V., V. N. Bringi, L. D. Cary, and S. Bolen, 1998, CSU-CHILL polarimetric meteorological radar measurements from a severe hailstorm in Eastern Colorado (including simultaneous Near-infrasonic measurements by A. J. Bedard in collaboration with E. A. Mueller), J. Appl. Meteor. Vol 37, pp. 749 – 775, 1998.
[18] Garces, M., P. Caron and Claus Hertzer, Infrasound from the 2004 – 2005 earthquakes and tsunami near Sumatra, Echoes – the newsletter of The Acoustical Society of America, Vol. 15, No. 4, p. , Fall 2005.